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CosmicProfiles: A Python package for radial profiling of finitely sampled dark matter halos and galaxies

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Software

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Summary

During the evolution of the Universe, dark matter clumps under its own gravitational influence and forms quasi-equilibrium halos. Their density and shape profiles are key to understanding the impact of exotic dark matter scenarios and the role baryonic feedback plays in the central regions of dark halos. Substantial simulation-based effort has been invested to model the approximately universal density profiles and to qualitatively track the evolution of shape profiles. The shapes of galaxies and their statistical correlations have recently received increased attention since the results of the next generation of weak lensing surveys such as Euclid will be contaminated by intrinsic alignment effects without a proper treatment thereof.

Statement of need

The analysis of simulation outputs that inform observational searches requires reliable and fast numerical tools. `CosmicProfiles` is a Python package with a substantial Cython component to enable quick and easy calculation of global and local density as well as shape properties of finitely resolved objects. Existing codes to extract density profiles include `SPARTA` (Diemer, 2022) while density profile fitting functionalities are provided by e.g. `Colossus` (Diemer, 2018). The strength of `CosmicProfiles` lies in shape profiling. The shape profiles of the objects can in turn be used to improve the fidelity of density profiles by considering ellipsoidal shells (defined via shape profiles) instead of the popular choice of spherical shells as the basis for the density profile extraction.

The objects under consideration can either be dark matter / gas halos or galaxies (stellar particles) from a cosmological simulation but also point clouds from any other scientific research field. The API for `CosmicProfiles` was designed to provide a class-based and user-friendly interface to Cython-optimized implementations of common operations such as the estimation of density profiles and subsequent fitting thereof to the user's preferred density profile model. Interfaces to `pynbody` (Pontzen et al., 2013) and `nbodykit` (Hand et al., 2018) have been rendered very simple with detailed example scripts, such that e.g. halos that have been identified via `pynbody` can be fed to `CosmicProfiles` for radial profiling.

If no halos are available to the user, `CosmicProfiles` offers a versatile mock halo generator that will sample particles from a target density profile model and ellipsoidal shape distribution, all provided by the user. `CosmicProfiles` was designed to be used by both astronomical researchers and researchers of other fields that come across spherical or ellipsoidal point clouds. It has already been used in a scientific publication (Dome et al., 2023). The combination of speed and design will hopefully ease the post-processing of simulation snapshots such as Gadget-style I, II or HDF5 files (Springel, 2010) and contribute to exciting scientific explorations by students and experts alike.

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